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EFFECTS OF FIRE AND FIRELINE DISTURBANCE ON THE PLANT COMMUNITY IN A SOUTHERN CALIFORNIA ECOLOGICAL RESERVE

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Abstract

Native plants in most California ecosystems are adapted to fire, but altered fire regimes and disturbance from firefighting activity, such as the construction of firebreaks or firelines, can change plant community composition and the ratio of native to nonnative species. In October 2007, a wildfire burned 710 acres through a chaparral/grassland mosaic on an ecological reserve, providing an opportunity to quantify fire and fireline disturbance impacts on native and nonnative species under differing disturbance conditions. In the spring of 2012 we sampled the plant community in three adjacent sites, focusing on *Centaurea melitensis*, which is a common nonnative invader after fire in California chaparral. The first site was burned and bulldozed, the second site was burned but not bulldozed, and the third site was not burned or bulldozed. The first site had also been sampled in the spring of 2008. After four years within the burned fireline site, the mean relative cover of *C. melitensis* decreased from 72% to 28%, but its density increased, and there were increases in the covers of nonnative annual grasses, litter, and native plants. Among the three sites in 2012, both of the burned sites had higher density and cover of *C. melitensis* and lower relative cover of annual grasses than the unburned site. The only site with notable native perennial presence was the burned fireline. The results of our study suggest that the recruitment of *C. melitensis* and some native species is promoted by fire. In the absence of additional disturbance by firelines, persistence of these taxa is limited by competition from nonnative annual grasses.

Key Words: California chaparral, *Centaurea melitensis*, disturbance, fire, firelines, invasive plants, Mediterranean ecosystems, nonnative annual grasses.

Fire has been a presence for thousands of years in southern California, from prehistoric infrequent lightning ignitions (Keeley and Fotheringham 2001) to Native American burning (Keeley 2002) to the relatively frequent anthropogenic fires of the present (Keeley and Fotheringham 2001). Although most native plants in California ecosystems are adapted to fire, fire frequency in many areas has increased beyond the extent of the natural regime, facilitating the recruitment of nonnative invaders (Hobbs and Huenneke 1992), supporting their persistence (Haidinger and Keeley 1993), and engendering the exclusion of native species (Keeley and Brennan 2012). Because of the threats to property, safety, and native biodiversity, California has an active approach to fire management, with practices such as the use of firebreaks or firelines that promote disturbances to plant communities. The disturbance effects of the construction and maintenance of firebreaks can promote nonnative plant colonization (D'Antonio et al. 1999; Merriam et al. 2006). The interaction of the effects of disturbance from firebreaks or firelines with impacts of frequent fire would be expected to additionally promote the colonization of nonnative annual species (Merriam et al. 2006).

The Sedgwick Reserve in the Santa Ynez Valley of Santa Barbara County, California, is part of the University of California Natural Reserve System. The land was used primarily for cattle grazing from the early 19th century until the site became a reserve in 1997. The Reserve supports coastal sage scrub, chaparral, native grassland, valley oak savanna, and other native vegetation communities but, perhaps due to the heavy disturbance associated with cattle grazing, these native communities have been invaded in some places by nonnative species. Wildfire had been excluded from the Reserve for at least 100 years when, in October 2007, a wildfire burned 710 acres through a chaparral/grassland mosaic on the Reserve. Protective firelines had been established at Sedgwick many years before. The Sedgwick Fire provided an opportunity to quantify fire and fireline disturbance impacts on native and invasive species under differing disturbance conditions.

Centaurea melitensis L. (Asteraceae) is a weedy annual forb that is native to the Mediterranean Basin and an aggressive invader in California shrublands and grasslands (Moroney and Rundel 2013). It is commonly observed after fire in California chaparral (Keeley et al. 2005). It can be dominant in disturbed areas, and has been found to out-compete native species (Moroney et al. 2011). In a comparative study of the demographics of *C. melitensis* in its native and

invasive ranges, a dense population of *C. melitensis* was found and surveyed in a burned fireline on the Sedgwick Reserve in the spring following the Sedgwick Fire (Moroney and Rundel 2013). We returned to the site four years later to quantify the changes in cover and density of *C. melitensis* and the associated plant community in the area disturbed by fire and the fireline. We also compared the cover and density of *C. melitensis* and the associated community composition in this site to an adjacent burned site with no fireline, and to an undisturbed (unburned, ungraded) site. Of particular interest was the comparative behavior of *C. melitensis* with nonnative annual grasses, which appear to competitively displace *C. melitensis* in California sites (Moroney and Rundel 2013).

The objectives of this study were to examine the relationship of disturbance events to patterns of native and nonnative dominance by asking the questions: (1) Does the native chaparral/grassland community recover in a burned fireline, or do nonnative species, *C. melitensis* in particular, persist and dominate?, and; (2) Does the post-fire community differ in sites with and without firelines, and do those sites differ from an undisturbed site? This was an opportunistic study with no replication of sites, so the results should be interpreted with this limitation in mind.

Methods

Study Species

Centaurea melitensis is an annual thistle that is native to the western Mediterranean Basin, but has been dispersed by humans and is invasive globally. It is a problem pest in California because it threatens the health of livestock and the persistence of native plants and animals (DiTomaso and Gerlach 2000; Moroney et al. 2011). It has been in California since at least 1797 (Hendry 1931). *Centaurea melitensis* is one of the most common nonnative plants in the first five years after fire in chaparral and coastal sage scrub of southern California, with an average density of >16,000 individuals ha^{-1} in chaparral sites and >285,000 individuals ha^{-1} in sage scrub sites (Keeley et al. 2005).

Study Sites

The Sedgwick Reserve, University of California Natural Reserve System (34°42′47.7″N, 120°02′00.7″W) contains a mix of vegetation types including chaparral, coastal sage scrub, native and nonnative grasslands, and valley oak savanna. The recorded fire history for the Reserve begins in 1912, and there have been no fires recorded on the Reserve until the 2007 Sedgwick Fire (S. Alderete, Santa Barbara County Fire Department, personal communication). Prior to the establishment of the Natural Reserve on the site the land was used for cattle grazing. We sampled three sites located on the Paso Robles Formation with a Shedd silty clay loam soil.

The first of the three sites (Burned, Fireline) was located along a ridge that was both burned and bulldozed during the 2007 Sedgwick Fire. A bulldozer cleared a one-blade width (12 ft) fireline on the ridgeline after the fire burned through the area to create access to the rest of the fire. This fireline was constructed several years before the Sedgwick Fire and had been intermittently maintained (S. Alderete, Santa Barbara County Fire Department, personal communication). In the spring following the fire (2008), we sampled the vegetation on the Burned, Fireline in association with a previous study that compared the density and dominance of *C. melitensis* in its native and invasive ranges (Moroney and Rundel 2013). We sampled this site again in the spring of 2012. The second site (Burned, No Fireline), sampled in the spring of 2012, was located along the same ridge immediately adjacent to the Burned, Fireline. This site burned in the Sedgwick Fire but was not disturbed by bulldozing. The third site (No Burned, No Fireline), also sampled in the spring of 2012, was 300 m south of the Burned, Fireline on the adjacent and parallel ridge, with a similar elevation, slope, and aspect. This site was not burned or disturbed in the Sedgwick Fire.

The two survey years, 2008 and 2012, had 739 mm and 577 mm of precipitation, respectively, during the rainy season (Lisque weather station, Sedgwick Reserve, 34.72449N, −120.0635W).

Sampling

In June 2008, sampling was conducted in the Burned, Fireline site. In June 2012, the same site was resampled, and the two additional sites were also sampled using two-stage systematic sampling (Elzinga et al. 1998). Ten transects were placed at randomly selected points within each 10 m increment of a 100 m baseline that followed the ridgeline. A series of 1 m × 0.2 m plots were placed at regular intervals along the transects starting at a randomly selected point. To determine population density of *C. melitensis*, individuals were counted within each plot. We estimated the percent cover of each of the following groups: *C. melitensis*, nonnative annual grasses, all nonnative species (including *C. melitensis* and annual grasses), all native species, litter, bare ground, and rock. Plot totals were averaged per transect. All taxa present in the plots were recorded.

TABLE 1. THE PRESENCE OF TAXA IN THE SAMPLE PLOTS REPORTED AS THE PERCENTAGE OF PLOTS IN EACH SITE. AF = Annual forb, S = Shrub, G = Geophyte, PG = Perennial grass, AG = Annual grass.

Species	Life-form	Percentage of plots			
		2008	2012	2012	2012
		Burned, Fireline	Burned, Fireline	Burned, No Fireline	No Burned, No Fireline
Native					
Adenostoma fasciculatum Hook. & Arn.	S	20	5	0	0
Amsinckia sp.	AF	0	0	5	15
Artemisia californica Less.	S	10	20	0	0
Calochortus sp.	G	25	0	0	0
Ceanothus sp.	S	35	5	0	0
Daucus pusillus Michx.	AF	0	0	10	0
Dichelostemma capitatum (Benth.) Alph. Wood	G	10	0	0	0
Galium sp.	AF	5	0	0	0
Hazardia squarrosa (Hook. & Arn.) Greene	S	0	0	0	20
Deinandra fasciculata (DC.) Greene	AF	0	0	25	0
Lupinus sp.	AF	0	0	30	0
Navarretia sp.	AF	0	0	30	0
Plantago erecta E. Morris	AF	0	0	10	0
Salvia mellifera Greene	S	0	5	0	0
Sisyrinchium bellum S. Watson	G	0	0	5	0
Stipa sp.	PG	15	40	5	15
Native species richness		7	5	8	3
Nonnative					
Anagallis arvensis L.	AF	70	35	25	0
Avena sp.	AG	0	15	100	100
Bromus sp.	AG	5	95	85	90
Carduus pycnocephalus L.	AF	0	5	0	10
Centaurea melitensis L.	AF	95	85	85	30
Erodium sp.	AF	35	45	60	30
Hordeum murinum L.	AG	0	25	25	30
Lactuca serriola L.	AF	0	0	5	25
Nonnative species richness		4	7	7	7
Total species richness		11	12	15	10

Statistical Analyses

To compare differences in the Burned, Fireline site between the sampling years 2008 and 2012, we performed a multivariate analysis using Hotelling's T^2 test on the following variables: relative cover of *C. melitensis*, relative cover of annual grass, relative cover of native plants, relative native species richness, percent cover of rock, percent cover of litter, and percent cover of bare ground. The multivariate test was followed by separate linear regressions for each variable. Relative cover was calculated as the percent cover of the target group divided by the total vegetative cover of all species in a plot. These variables were arcsine-square root transformed to stabilize the variance and then back-transformed to proportions for interpretation. The difference in *C. melitensis* density between years was analyzed with a Poisson regression with robust standard errors.

To compare differences in the three sites in 2012 (Burned, Fireline, Burned, No Fireline, and No Burned, No Fireline), we used the same analytical approach as above, substituting MANOVA for Hotelling's T^2 in the multivariate analysis. The linear regressions were followed by *post hoc* testing using multiple comparisons with bonferroni corrections to test for the differences in predicted means between pairs of sites. All statistical analyses were done using Stata statistical software (Stata, version 12.1, Statacorp, College Station, TX).

RESULTS

A total of 24 species were recorded in the plots over all sites and years collectively, including 16 native species and eight nonnative species. Native life forms included seven annual forb species, five shrub species, three geophytes, and one perennial grass. There were no native annual grasses. All of the nonnative plants were annuals, with five annual forb species and three annual grass species (Table 1). *Centaurea melitensis* was the most common species in all of the sites collectively (74% of the plots).

Fireline Between Years

There was a significant difference in the relative cover composition of the community

TABLE 2. TWO POISSON REGRESSION MODELS WITH ROBUST STANDARD ERRORS COMPARING *CENTAUREA MELITENSIS* DENSITY WITHIN THE BURNED, FIRELINE BETWEEN YEARS AND BETWEEN YEARS AMONG SITES. 2008 is the reference year in the first model, and the Burned, Fireline is the reference site in the second model. *P < 0.001.

Source	Coefficient	X^2	P
Burned, Fireline between years			
Year	0.677	3.881	0.049
Constant	2.5	107.537	*
Sites within year			
Site 2	0.347	0.846	0.356
Site 3	−2.736	15.761	*
Constant	3.174	170.825	*

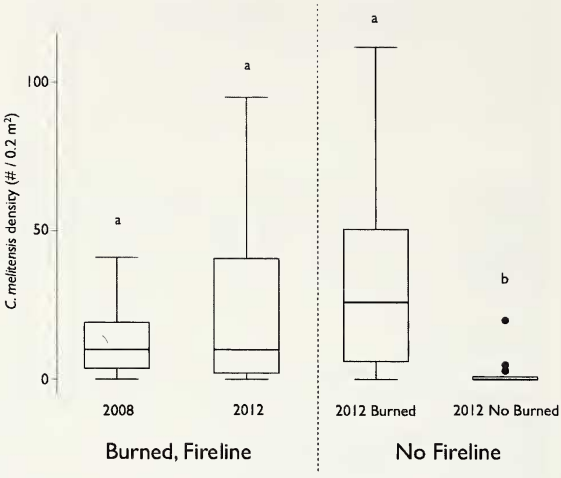

FIG. 1. Density box plots of *C. melitensis* measured in four sites at the Sedgwick Reserve. The two boxes on the left represent sites within a bulldozed fireline, with data measured in 2008 and 2012. The two boxes on the right represent two sites adjacent to the fireline, but not bulldozed, one burned site and one unburned site, with data measured in 2012.

within the Burned, Fireline in 2012 compared to 2008 (2-group Hotelling's T^2, F = 14.495, P = 0.0001). This difference was due to a decrease in the relative cover of *C. melitensis*, an increase in the relative cover of annual grasses, an increase in the relative cover of native plants, and an increase in the percent cover of litter (Table 2). The density of *C. melitensis* increased despite the decrease in relative cover (Fig. 1). There was no change in native species richness.

The number of plots with native shrubs, geophytes, and annual forbs decreased in four years, but the number of plots with native perennial grasses increased (Table 1). In 2008, the most common natives were shrub seedlings, but the most common group in 2012 was perennial grasses. All of the shrub species recorded in 2008 were still present in 2012 and the number of shrub species found within the Burned, Fireline increased from three to four. Overall, native species recovery was positive with an increase in native species relative cover and no significant change in native species richness.

Sites Within Year

The three sites (Burned, Fireline, Burned, No Fireline, and No Burned, No Fireline) differed significantly in community relative cover composition (Pillai's trace; $F_{2,27} = 44$; P < 0.0001). The No Burned, No Fireline site had lower relative cover and density of *C. melitensis* and higher relative cover of annual grasses than both the Burned, Fireline site and the Burned, No Fireline site (Table 3, Fig. 1). The Burned, Fireline had higher percent cover of both rock and bare ground than either of the other two sites. The percent cover of litter was significantly higher in the Burned, No Fireline site than the Burned, Fireline site, but not different from the No Burned, No Fireline site (Table 3). There was no difference among the sites in relative cover of natives or in native species richness.

All of the native species in the Burned, Fireline were perennials, with four shrub species and one perennial grass species. The native species in the Burned, No Fireline site were mostly annual forbs, with one perennial grass, one geophyte, and no shrubs. In the No Burned, No Fireline site, the natives included one annual forb species, one shrub species, and one perennial grass (Table 1).

DISCUSSION

Four years after the disturbances of fire and bulldozing, the mean relative cover of *Centaurea melitensis* decreased significantly, from 72% to 28%, within the Burned, Fireline. In contrast, the cover of annual grasses increased in four years from almost zero to a mean cover of 6%. Litter also increased significantly, from a mean cover of 10% in 2008 to 29% in 2012. Despite the decrease in relative cover of *C. melitensis*, the density remained the same. The same number of individuals germinated and survived, but they were smaller in size. This could have been due to the reduction in water availability in 2012 compared to 2008, or to competition with annual grasses that were not present in 2008. This suggests that even after severe disturbances such as fire and bulldozing that reduce the cover of annual grasses, these grasses can quickly regain dominance and displace annual forbs.

The differences in the three sites in 2012 were most dramatic in the relative cover and frequency of *C. melitensis*. While both of the Burned sites had more than 25% cover and 85% frequency of

Table 3. Seven Linear Regression Models for the Effect of Year Within the Burned, Fireline on Each of the Following Variables: *C. melitensis* density, the Relative Cover of *C. melitensis*, Annual Grasses, Nonnative Plants, Native Plants, Relative Native Richness, and the Percent Cover of Litter, Rock, and Bare Ground. The coefficients are predicted values for each year. The constant is the intercept. The reference year is 2008. *P <0.001.

Source	Coefficient	t	P
Relative cover of *C. melitensis*			
Year	−0.547	−5.86	*
Constant	1.066	16.13	*
Relative cover of annual grass			
Year	0.5	8.35	*
Constant	0.017	0.41	0.689
Relative cover of native plants			
Year	0.347	2.84	0.011
Constant	0.228	2.65	0.016
Relative native richness			
Year	−0.018	−0.14	0.889
Constant	0.463	5.13	*
Percent cover of rock			
Year	−0.082	−2	0.061
Constant	0.185	6.38	*
Percent cover of litter			
Year	0.235	3.59	0.002
Constant	0.318	6.87	*
Percent cover of bare ground			
Year	−0.05	−0.51	0.618
Constant	0.667	9.54	*

C. melitensis, the 2012 No Burned, No Fireline site had only 5% cover and 30% frequency. This suggests that the disturbance caused by fire, regardless of the additional clearing by bulldozer, opens colonization sites sufficiently for *C. melitensis* to establish. The increased frequency and cover of annual grasses in the Burned, Fireline site after four years suggests that propagules from nearby unburned patches of annual grass colonize cleared sites over time. The lower cover of *C. melitensis* in the No Burned, No Fireline site may be linked to the increase in annual grass cover and associated litter over time, as their relative covers seem to have a somewhat inverse relationship. Once seeds are present, annual grasses germinate and grow tall earlier in the season than *C. melitensis*, possibly blocking out light and preempting germination potential. Litter accumulation may also suppress germination by limiting light and changing the temperature and moisture availability on the soil surface (Carson and Peterson 1990).

Of the three sites sampled in 2012, the Burned, Fireline had the lowest relative cover of annual grasses and the highest relative cover of *C. melitensis*. This site also had the lowest nonnative relative cover and the highest native relative cover. This may be related to the depth of the seed banks of annual grasses and *C. melitensis*. Smaller seeds are generally shallower in the soil than heavier seeded species, and thus more vulnerable to mortality from fire (Bond et al. 1999). If heavier, more compact *C. melitensis* seeds are buried deeper in the soil, while lighter grass seeds stay nearer the soil surface, then both the fire intensity and the depth of the bulldozer blade might have been factors in the reduction of annual grasses and the persistence of *C. melitensis*. High intensity, warm-season fires can kill annual grass seeds on the surface of the soil and increase the cover of native species (Meyer and Schiffman 1999). Furthermore, the bulldozer might have cleared surface seeds, exposing the deeper *C. melitensis* seeds to the surface. Alternatively, clearing the litter may have been the more important effect of bulldozing and fire. With barriers to germination removed, *C. melitensis* and native seeds in the seed bank would have had an opportunity to recruit. The disturbances of fire and bulldozing might reduce annual grasses and recover forbs and shrubs in the short term as long as the seed bank is deep enough and remains intact.

Woody plant canopy closure (i.e., native shrubs) has been shown to be the most important direct factor in explaining alien plant dominance in southern California chaparral and sage scrub sites within five years after fire (Keeley et al. 2005). The only site with substantial woody plant recruits four years after fire was the Burned, Fireline, with no shrubs in the Burned, No Fireline site, and the No Burned, No Fireline site supporting only a few small individuals of one shrub species, *Hazardia squarrosa* (Hook. & Arn.) Greene. In 2008, the shrubs recorded in the Burned, Fireline were seedlings, as the soil surface had been graded, removing all mature shrubs that might have been present. Four years after the fire, shrubs growing in the Burned, Fireline were still relatively small, and annual plant cover was high, suggesting that none of the shrubs in the Burned, Fireline were large enough to close the canopy sufficiently to shade out annual plants.

Fire frequency is an important determinant of the relative success of native versus nonnative species in chaparral. In sites that burn at intermediate fire frequencies, total species diversity is typically highest in the first few years following fire (Keeley and Fotheringham 2003). In sites that have burned at high frequency, nonnative annuals dominate after fire, but in sites that have not burned for several decades, native annuals dominate after fire (Haidinger and Keeley 1993). At Sedgwick Reserve fire has been absent for at least 100 yr. However, in the first four years after a fire, nonnative annuals dominated. Perhaps

the disturbance from past grazing has been a factor in determining the present composition of the community and the high relative cover of nonnative species. Due to sampling design limitations, our results must be interpreted with caution. However, our data can be useful to management of disturbed areas. The results indicate that in these sites, fire promoted native species diversity, and the Burned, Fireline had the most native perennials. Multi-year monitoring of the community is important to assess the fate of early colonizers after such disturbances. The results of our study suggest that the recruitment of *C. melitensis*, along with some native species, is promoted by fire. Over time, its abundance is limited by competition, not from woody native species, but from another group of nonnative invaders, Mediterranean annual grasses.

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